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Impact of Glomalin-Related Soil Proteins on *in vitro* Finger Millet (*Eleusine coracana* (L.) Gaertn.) seed germination

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ABSTRACT: Arbuscular mycorrhizal fungi (AMF) form symbiotic relationships with approximately 80% of terrestrial plants, enhancing root surface area and interacts with the rhizosphere. Glomalin-related soil protein (GRSP), a glycoprotein secreted by AMF, influences soil quality and promotes plant growth. This study investigates the effects of exogenously applied GRSP on finger millet seed germination *in vitro*. Two concentrations of GRSP were administered to observe its effect on root length, shoot length, and biomass production. Results showed that half-strength GRSP significantly enhances seedling growth, while full-strength exhibited zero to inhibitory effects. The root growth, shoot growth, biomass and seedling vigour index increased in GRSP treated MS media compared to control by nearly 70%, 81%, 43% and 75 % respectively. Comparative studies suggested a parallel perspective on the growth-promoting role of GRSP. The positive impact of EE-GRSP on finger millet seeds aligns with its humic acid-like properties, yet higher concentrations may contain impurities hindering growth. Hence, this study exhibits that GRSP is a potential growth promoter for finger millet.

Key words: Arbuscular mycorrhizal fungi (AMF), finger millet, seed germination

Arbuscular mycorrhizal fungi (AMF) form symbiotic relationships with almost 80% of land plants. Once established within the roots of these plants, AMF extend extraradical hyphae into the surrounding soil, effectively increasing the root surface area and enhancing interaction with the rhizosphere (Ahanger *et al.*, 2014; Begum *et al.*, 2019). A key component of this symbiosis is the secretion of a glycoprotein, now referred to as Glomalin-Related Soil Protein (GRSP), formerly known as Glomalin, which significantly contributes to soil quality improvement, including physical properties, carbon sequestration, nutrient levels, microbial activities, pollutant stabilization, and ecological restoration (Holátko *et al.*, 2021, ; Halvorson and Gonzalez, 2006 ;Wright and Upadhyaya, 1998). GRSP has also been observed to enhance root and shoot length in various pot experiments (Wang *et al.*,2015).

The utilization of GRSP for promoting plant tissue growth and morphogenesis in controlled *in vitro* conditions is an emerging field. Factors such as culture medium composition, carbon source,

genotype, explant type and growth conditions influence tissue culture responses (Morrish *et al.*, 1987; Kothari *et al.*, 2004). Adjustments to salt composition or growth regulators can improve seed germination and plant regeneration. Protocols for *in vitro* seed germination and seedling development have been established for various species, including *Bobgunnia madagascariensis*, *Pterocarpus marsupium* and *Cordeauxia edulis*, involving different basal media, salt strengths, growth regulator types and concentrations, and the use of mature and immature seeds (Koné, 2015). In our study, finger millet (*Eleusine coracana* (L.) Gaertn.) seeds were chosen due to their adaptability in diverse culinary applications and well-documented exceptional nutritional value (Latha *et al.*, 2005). “Sprouted finger millet seeds offer a high nutritional value and are also easy to digest.” Therefore, investigating any potential positive influence of GRSP on seed germination through field studies holds promise for enhancing the nutritional quality of finger millet. Until now, there has been a dearth of information concerning the impact of applying exogenous GRSP on seed germination in *in-vitro* settings. Hence, the

primary objective of this study is to administer GRSP at two concentrations to finger millet seeds and assess their effects on root length, shoot length and biomass production.

MATERIALS AND METHODS

Seed source and sterilization

Seeds of Finger millet (var. VLM- 379) were obtained from Vivekanad Parvatiya Krishi Anusandhan, Almora, Uttarakhand. The seeds were washed under running tap water for 20 min and then treated with surfactant Tween 20 (0.1% v/v) for 10 min. with constant agitation. The seeds were further sterilized in 0.1% (w/v) HgCl₂ solution for 3 min. and then washed 6-7 times with autoclaved distilled water (Hussain *et al.*, 2017).

GRSP extraction

For each gram of soil (collected from a 15-year-old Dalbergia sissoo tree rhizosphere in the Agroforestry Research Center, Pantnagar, Uttarakhand, India), 8 ml of 20 mM sodium citrate (pH 7) buffer was added and then autoclaved for 40 minutes at 121°C.

The mixture was then centrifuged for 20 minutes at 5000 rpm, and the supernatant was collected for EE-GRSP determination (Wright and Upadhyaya, 1996). The protein concentration in the supernatant was quantified using the Lowry assay (Lowry *et al.*, 1951).

Media preparation and experimental set up

Murashige and Skoog basal medium with 3% sucrose and 0.7% agar (HiMedia, Mumbai, India) was used as a standard medium in which extracted GRSP was added. Three types of media are prepared. For making a) Full strength GRSP medium, 10 ml GRSP (1336.7 µg GRSP/ml) was added into 40 ml basal MS. b) Half strength GRSP medium was prepared by adding 10 ml GRSP (667.9 µg GRSP/ml) into 40 ml basal MS and the control was made by mixing 10 ml acetate buffer with 40 ml basal MS. The pH of the media was adjusted to 5.8 and the media was autoclaved for 18 min at 1.2– 1.3 kg cm⁻² and 121°C. Sterilized seeds were inoculated on the media. The cultures were kept in a culture chamber with a photoperiod of 16 h (2000 lux) at 25 fC. The

observations were recorded on the 21st day from the inoculation.

Seed germination parameters

- Germination percentage (G%): (number of seeds germinated × 100) / total number of seeds (Iqbal *et al.* 2016)
- Root and shoot length: Root and shoot length were recorded in centimeter (cm) Mean root and shoot length were compared in form of bar chart.
- Seedling vigour index (SVI): Seedling vigour index was calculated and expressed according to Abdul-Baki and Anderson, 1973; Ushahra and Malik, 2013 using following formula.

$$SVI = [\text{root length (cm)} + \text{shoot length (cm)}] \times \text{germination percentage}$$
- Seeds inoculated in solidified MS medium without any GRSP incorporation was taken as control. Seed germination was calculated at the end of the experiment. All seeds were grown on solidified MS medium.

Statistical analysis

Each treatment consisted of 10 seeds in three different jam bottle and results were interpreted as mean ± standard deviation. The statistical analysis of the experimental data used ANOVA and Tukey's post hoc test at p<0.05. Each experimental value was compared with the control.

RESULTS AND DISCUSSION

Germination percentage

The effect of exogenously applied GRSP on seed germination is shown in Figure 1. Germination was 100% across all three setups. Finger millet seeds generally sprout with extended time period and very few seeds fail to germinate (Kumar *et al.*, 2021)

Root and shoot length and seedling vigour index (SVI)

It is evident that exogenously applied GRSP has a positive effect as compared to control on root length, shoot length, biomass and SVI. Root length, shoot length and SVI however have a similar growth in case of full strength GRSP (Figure 1). Half-strength

GRSP had the best result among the three. The root growth, shoot growth, biomass and seedling vigour index increases in GRSP treated MS media compared to control was nearly 70%, 81%, 43% and 75% respectively (Table 1).

The previous studies on the exogenous application of GRSP were not conducted *in vitro*. However, insights from studies conducted in pots provide a parallel perspective, indicating that half-strength exogenous GRSP significantly enhances the performance of plant growth (Guo *et al.*, 2023). They further noted marked improvements in biomass and root system architecture traits, encompassing root surface area, volume, taproot length, and lateral root numbers in lemon seedlings. Subsequently, another study chose to utilize 1/2-strength exogenous GRSP on potted trifoliolate orange seedlings subjected to drought stress. Their study illuminated the significant promotion of growth performance and biomass in plants, coupled with the alleviation of water stress. These positive outcomes were associated with increased leaf water potential and the altered expression of ABA and IAA, collectively contributing to enhanced water uptake (Chi *et al.*, 2018).

Building upon this foundation, another study extends the understanding of exogenous GRSP application by demonstrating its significant positive impact on the plant growth performance of lemon seedlings. This observation (Fig. 2 and 3) resonates with prior research (Wang *et al.*, 2015; Liu *et al.*, 2021) on trifoliolate orange seedlings. Additionally, the study underscores the significance of application strength, with 3/4-strength exogenous EE-GRSP showing the most pronounced positive effect on plant growth. In



Fig. 1: The germinated seeds after conclusion of experiment. A) Control, B) Half strength GRSP and C) Full strength GRSP

contrast, 1/2-strength exogenous EE-GRSP applications exhibited superior performance in facilitating plant biomass. These findings align seamlessly with earlier research in the field.

The ability of GRSP to promote plant growth is posited to be intricately linked with the presence of humic acid, a known enhancer of growth in various plants such as pea and maize (Basha *et al.*, 2020; Rajamani *et al.*, 2021) respectively. Additionally, Schindler *et al.* (2007) discovered that GRSP is composed of a diverse array of substances, including aromatic hydrocarbons (42~49%), carboxylic acid groups (24~30%), carbohydrates (4~16%), and low aliphatic and carbon (4~11%). Strikingly, these components bear a remarkable resemblance to the structure of humic acid, further highlighting the potential role of humic acid in the growth-promoting capabilities of GRSP.

In our study, a nuanced exploration of seed germination responses in finger millet to the exogenous application of two GRSP fractions revealed intriguing patterns. Notably, half-strength GRSP exhibited a robust promotion of plant growth, while full-strength GRSP yielded no significant effect. These outcomes strongly suggest that GRSP might function as a growth promoter for finger millet seeds. This finding echoes the results observed by Wang *et al.* (2015). According to Gadkar and Rillig (2006) a well-established association of GRSP with humic acid, akin to NMR spectrum-based humic acid findings by Schindler *et al.* (2007), further supports the notion that EE-GRSP, with its humic acid-like substance, contributes to the enhancement of plant growth.

Table 1: Effect of exogenously applied GRSP on *in vitro* seeds germination of finger millet

Treatment	Germination %	Seedling vigour index (SVI)
Control	100	868 ±89.61 ^b
Half Strength EE- GRSP	100	1522.67 ± 79.53 ^a
Full Strength EE-GRSP	100	710.34 ±82.85 ^c

Note: means followed by different superscript are significantly different at $p < 0.05$.

Conversely, the application of full strength GRSP resulted in stunted growth, with inhibitory effects intensifying with higher concentrations of exogenous GRSP. This suggests the presence of more impurities in -GRSP that may be detrimental to plant growth. However, the nature of these impurities remains unclear, as elucidated by Gillespie *et al.* (2011).

Similar inhibitory results in lemon by full strength GRSP are reported by Sade *et al.* (2009). They concluded that the application of full-strength GRSP has been found to produce similar inhibitory effects, as observed with high-strength exogenous GRSP treatments, resulting in a significant decrease in the

expression of tonoplast intrinsic proteins (TIPs). TIPs are known to play a crucial role in regulating water content and absorption capacity in plants. Generally, higher expression levels of TIPs indicate better water absorption and regulation capabilities.

According to Ruiz-Lozano *et al.* (2010) when exogenous GRSP is applied, it leads to an increase in soil solution concentration, inducing dehydration stress in lemon seedlings. This stress triggers an upsurge in TIPs expression in the plant, aiming to enhance membrane permeability and facilitate water transport within the plant. However, under high-strength exogenous GRSP applications, the expression of TIPs is down-regulated, possibly due to a reduction in membrane permeability, thus helping to maintain cellular hydration. Alternatively, it is suggested by Šurbanovski *et al.* (2013), that high-strength exogenous GRSP applications may regulate the stability or down-regulation of TIP genes to mitigate water dissipation and prevent water reflux into dry soil. This highlights the complexity of the interactions between GRSP, its components, and their influence on plant responses. Further research is warranted to unravel the specific nature of these impurities and their role in mediating undesirable plant responses.

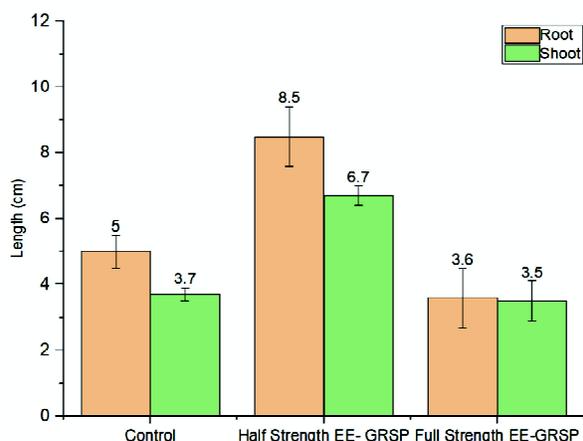


Fig. 2: Root and shoot growth against Control, Half strength EE-GRSP and Full strength EE-GRSP

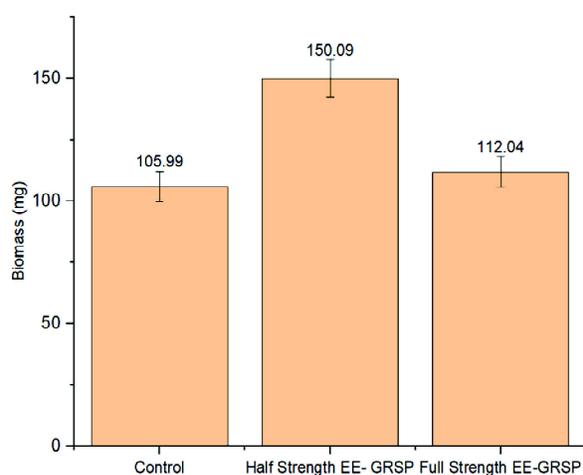


Fig. 3: Biomass accumulation against Control, Half strength EE-GRSP and Full strength EE-GRSP

Root length, shoot length, biomass and seedling vigour index all show strong and positive correlation

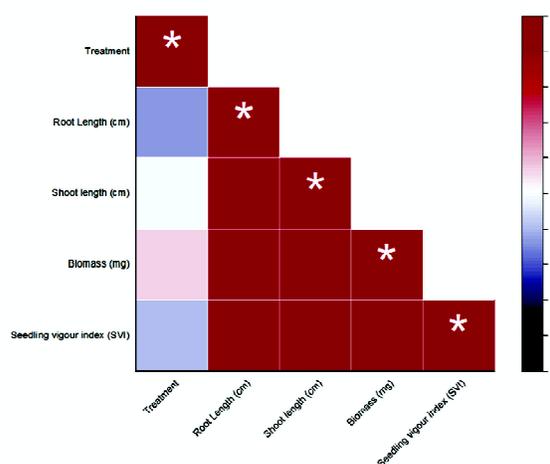


Fig. 4: Correlation matrix between various parameters. Red box shows strong correlation while blue box shows negative correlation

with each other (Figure 4). The changes with treatment, however shows some mild correlation with the estimated parameters which can be understood from Table 1 as the best result is shown by half GRSP concentration and a full GRSP concentration results in a decrement in all the parameters. The matrix clearly shows that using a half concentration of GRSP is beneficial for increasing root, shoot and biomass in *in-vitro*. These correlations offer valuable insights into the relationships among these parameters, which can enhance understanding of plant growth and development under different treatments.

The present study introduces an innovative approach to incorporate GRSP *in vitro* for seed germination. The findings suggested that seed germination is influenced by the exogenous application of GRSP at varying concentrations. In the present study it is very evident that half-strength GRSP (667.9 µg GRSP/ml) gives the best result. Exogenously applied GRSP may induce distinct effects on the plant growth response of finger millet. These outcomes hint at the prospective use of GRSP as a plant growth promoter in the context of finger millet production. It is essential to conduct further field studies, along with a thorough investigation of the physiological mechanisms underlying GRSP's effects and the growth responses it mediates. Such in-depth research is crucial before GRSP can be considered a standard agricultural practice or technological advancement. Based on these findings, additional exploration of GRSP as a plant growth promoter, particularly for finger millet production, is recommended. To validate these results and confirm GRSP's viability as an agricultural tool, further field studies are necessary. These should focus on the physiological processes involved and the overall impact of GRSP on plant growth. Comprehensive research will provide a deeper understanding of GRSP's functionality and support its integration into established field practices and innovations.

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REFERENCES

- Abdul Baki, A.A. and Anderson, J.D. (1973). Vigor determination in soybean seed by multiple criteria 1. *Crop Science*, 13(6):630-633.
- Ahanger, M. A., Tyagi, S. R., Wani, M. R. and Ahmad, P. (2014). Drought tolerance: role of organic osmolytes, growth regulators, and mineral nutrients. Physiological mechanisms and adaptation strategies in plants under changing environment, 1: 25–55.
- Basha, D.M.A., Hellal, F. and El-Sayed, S. (2020). Effects of Potassium and Humic Acid on Amelioration of Soil Salinity Hazardous on Pea Plants. *Asian Journal of Soil Science and Plant Nutrition*, 5:1–10.
- Begum, N., Qin, C., Ahanger, M.A., Raza, S., Khan, M.I., Ashraf, M., Ahmed, N. and Zhang, L., 2019. Role of arbuscular mycorrhizal fungi in plant growth regulation: implications in abiotic stress tolerance. *Frontiers in Plant Science*, 10:1068.
- Chi G.G., Srivastava A.K. and Wu Q.S. (2018). Exogenous easily extractable glomalin-related soil protein improves drought tolerance of trifoliolate orange. *Archives of Agronomy and Soil Science*, 64:1341–1350.
- Gadkar, V. and Rillig, M. C. (2006). The arbuscular mycorrhizal fungal protein glomalin is a putative homolog of heat shock protein 60. *Federation of European Microbiological Societies*, 263: 93–101.
- Gillespie, A.W., Farrell, R.E., Walley, F.L., Ross,

- A.R., Leinweber, P., Eckhardt, K.U., Regier, T.Z. and Blyth, R.I., (2011). Glomalin-related soil protein contains non-mycorrhizal-related heat-stable proteins, lipids and humic materials. *Soil Biology and Biochemistry*, 43(4):766-777.
- Guo, X.N., Hao, Y., Wu, X.L., Chen, X. and Liu, C.Y. (2023). Exogenous easily extractable glomalin-related soil protein stimulates plant growth by regulating tonoplast intrinsic protein expression in lemon. *Plants*, 12(16): 2955.
- Halvorson, J.J. and Gonzalez, J.M. (2006). Bradford reactive soil protein in Appalachian soils: distribution and response to incubation, extraction reagent and tannins. *Plant and Soil*, 286: 339–356.
- Holátko, J., Brtnický, M., Kučerík, J., Kotianová, M., Elbl, J., Kintl, A., Kynický, J., Benada, O., Datta, R. and Jansa, J. (2021). Glomalin—Truths, myths, and the future of this elusive soil glycoprotein. *Soil Biology and Biochemistry*, 153: 108116.
- Hussain, M., Raja, N.I., Mashwani, Z.U.R., Iqbal, M., Sabir, S. and Yasmeen, F. (2017). In vitro seed germination and biochemical profiling of *Artemisia absinthium* exposed to various metallic nanoparticles. *3 Biotech*, 7:1-8.
- Iqbal, M., Asif, S., Ilyas, N., Raja, N.I., Hussain, M., Shabir, S., Faz, M.N.A. and Rauf, A. (2016). Effect of plant derived smoke on germination and post germination expression of wheat (*Triticum aestivum* L.). *American Journal of Plant Sciences*, 7(6):806-813.
- Koné, M., Koné, T., Silué, N., Soumahoro, A.B. and Kouakou, T.H., (2015). In vitro seeds germination and seedling growth of Bambara groundnut (*Vigna subterranea* (L.) Verdc.(Fabaceae)). *The Scientific World Journal*.
- Kothari, S.L., Agarwal, K. and Kumar, S. (2004). Inorganic nutrient manipulation for highly improved in vitro plant regeneration in finger millet—*Eleusine coracana* (L.) Gaertn. *In Vitro Cellular & Developmental Biology-Plant*, 40: 515-519.
- Kumar, A., Kaur, A., Gupta, K., Gat, Y. and Kumar, V. (2021). Assessment of germination time of finger millet for value addition in functional foods. *Current Science*, 120(2):406-413.
- Latha, A.M., Rao, K.V. and Reddy, V.D. (2005). Production of transgenic plants resistant to leaf blast disease in finger millet (*Eleusine coracana* (L.) Gaertn.). *Plant Science*, 169(4): 657-667.
- Liu, R.C, Gao, W.Q., Srivastava, A.K., Zou, Y.N., Kuča, K., Hashem, A., Abd_Allah, E.F. and Wu, Q.S. (2021). Differential effects of exogenous glomalin-related soil proteins on plant growth of trifoliolate orange through regulating auxin changes. *Frontiers of Plant Science*, 12:745402.
- Lowry, O.H., Rosebrough, N.J., Farr, A.L. and Randall, R.J. (1951). Protein measurement with the Folin phenol reagent. *Journal of Biological Chemistry*, 193 (1): 265-275
- Morrish, F., Vasil, V. and Vasil, I.K. (1987). Developmental morphogenesis and genetic manipulation in tissue and cell cultures of the Gramineae. *Advances in Genetics*, 24: 431-499.
- Murashige, T. and Skoog, F. (1962). A revised medium for rapid growth and bio assays with tobacco tissue cultures. *Physiologia Plantarum*, 15(3).
- Rajamani, K., Reddy, K.I. and Srinivas, A. (2021). Influence of Super Absorbent Polymer and Humic Acid on Maize Yield and Nutrient Uptake on Rainfed Alfisols. *International Journal of Environment and Climate Change*, 11:97–106.
- Ruiz-Lozano J.M. and Aroca R (2010). *Symbioses and Stress: Joint Ventures in Biology*. Springer; Dordrecht, The Netherlands. Modulation of Aquaporin Genes by the Arbuscular Mycorrhizal Symbiosis in Relation to Osmotic Stress Tolerance: Aquaporin in AM Plants Under Osmotic Stress, Pp 357–374.
- Sade N., Vinocur B.-J., Diber A., Shatil A., Ronen G., Nissan H., Wallach R., Karchi H., Moshelion M. (2009). Improving plant

- stress tolerance and yield production: Is the tonoplast aquaporin SITIP2; 2 a key to isohydric to anisohydric conversion? *New Phytologist*, 181:651–661.
- Schindler, F. V., Mercer, E. J. and Rice, J. A. (2007). Chemical characteristics of glomalin-related soil protein (GRSP) extracted from soils of varying organic matter content. *Soil Biology and Biochemistry*, 39:320–329.
- Šurbanovski, N., Sargent, D. J., Else, M. A., Simpson, D. W., Zhang, H. and Grant, O. M. (2013). Expression of *Fragaria vesca* PIP aquaporins in response to drought stress: PIP down-regulation correlates with the decline in substrate moisture content. *PLoS one*, 8(9):e74945.
- Ushahra, J. and Malik, C.P. (2013). Putrescine and ascorbic acid mediated enhancement in growth and antioxidant status of *Eruca sativa* varieties. *CIBTech Journal of Biotechnology*, 2:53-64.
- Wang, S., Wu, Q. S., and He, X. H. (2015). Exogenous easily extractable glomalin-related soil protein promotes soil aggregation, relevant soil enzyme activities and plant growth in trifoliolate orange. *Plant, Soil and Environment*, 61: 66–71.
- Wright, S.F. and Upadhyaya, A. (1996). Extraction of an abundant and unusual protein from soil and comparison with hyphal protein of arbuscular mycorrhizal fungi. *Soil Science*, 161: 575–586.
- Wright, S.F. and Upadhyaya, A. (1998). A survey of soils for aggregate stability and glomalin, a glycoprotein produced by hyphae of arbuscular mycorrhizal fungi. *Plant and Soil*, 198: 97–107.

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